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Wang et al.

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(54) **FACILITATING DATA REDISTRIBUTION IN DATABASE SHARDING**

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G06F 7/00 (2006.01)
G06F 17/30 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 17/3033*** (2013.01); ***G06F 17/30194*** (2013.01); ***G06F 17/30289*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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Primary Examiner — Michael Hicks
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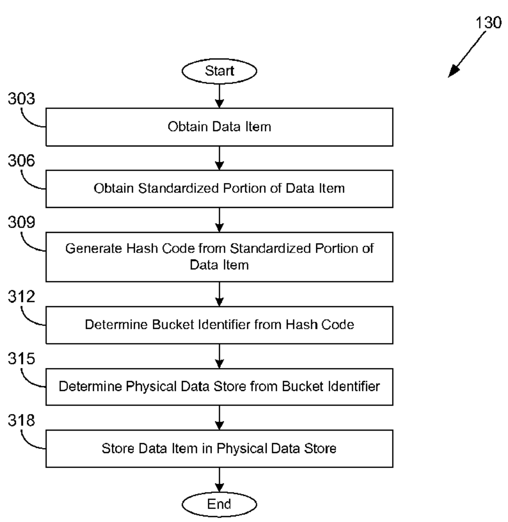
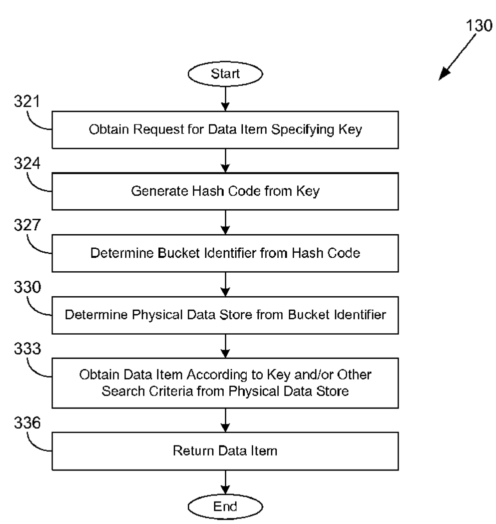
(57) **ABSTRACT**

Disclosed are various embodiments for facilitating data redistribution in database sharding. A database is maintained that is horizontally partitioned into a set of first buckets using modulo-based assignments. A fixed number of the first buckets are stored in each of multiple physical data stores. The database is repartitioned into a set of second buckets using modulo-based assignments. The number of second buckets in the set is a multiple of the sum of a positive integer and the quantity of the physical data stores. The data in the database is unmoved between the physical data stores by repartitioning.

20 Claims, 7 Drawing Sheets





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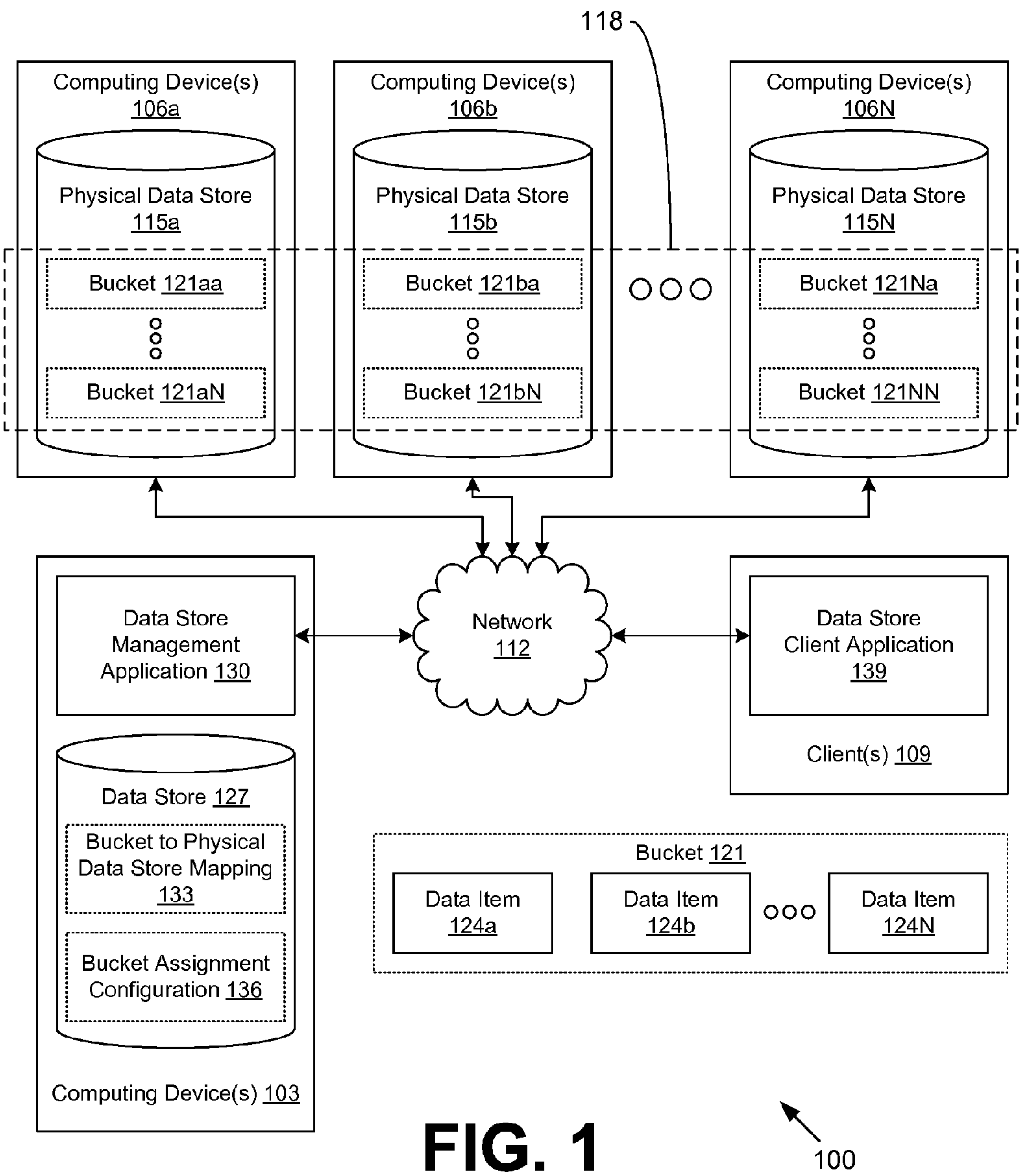
118
Computing Device(s)
106a
Physical Data Store
115a
Bucket 121aa
Bucket 121aN
Computing Device(s)
106b
Physical Data Store
115b
Bucket 121ba
Bucket 121bN
Computing Device(s)
106N
Physical Data Store
115N
Bucket 121Na
Bucket 121NN
Data Store
Management
Application 130
Network
112
Data Store
Client Application
139
Client(s) 109
Data Store 127
Bucket to Physical
Data Store Mapping
133
Bucket Assignment
Configuration 136
Computing Device(s) 103
Bucket 121
Data Item
124a
Data Item
124b
Data Item
124N
100

FIG. 1

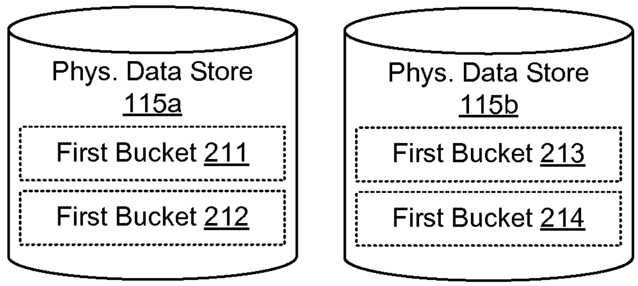
Phys. Data Store 115a
First Bucket 211
First Bucket 212
Phys. Data Store 115b
First Bucket 213
First Bucket 214

FIG. 2A

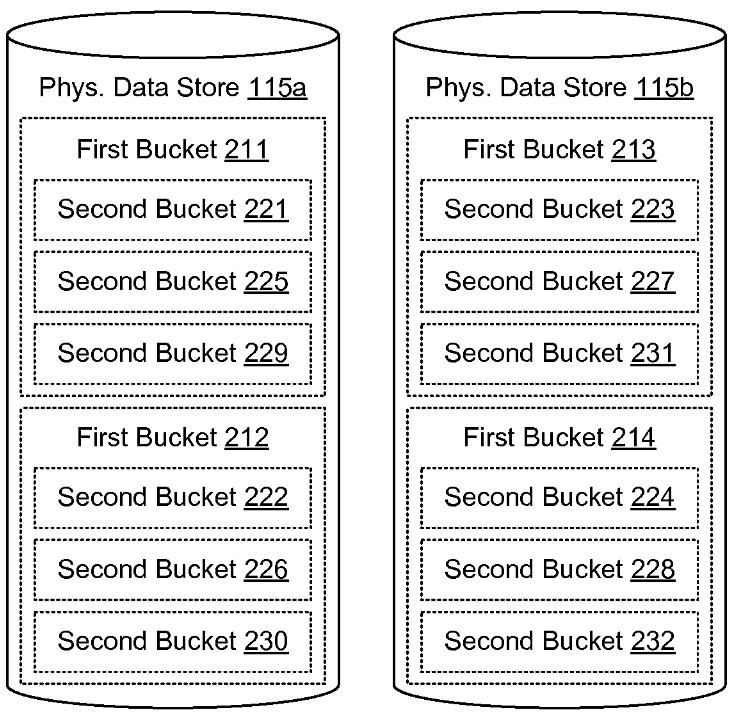
Phys. Data Store 115a
First Bucket 211
Second Bucket 221
Second Bucket 225
Second Bucket 229
First Bucket 212
Second Bucket 222
Second Bucket 226
Second Bucket 230
Phys. Data Store 115b
First Bucket 213
Second Bucket 223
Second Bucket 227
Second Bucket 231
First Bucket 214
Second Bucket 224
Second Bucket 228
Second Bucket 232

FIG. 2B

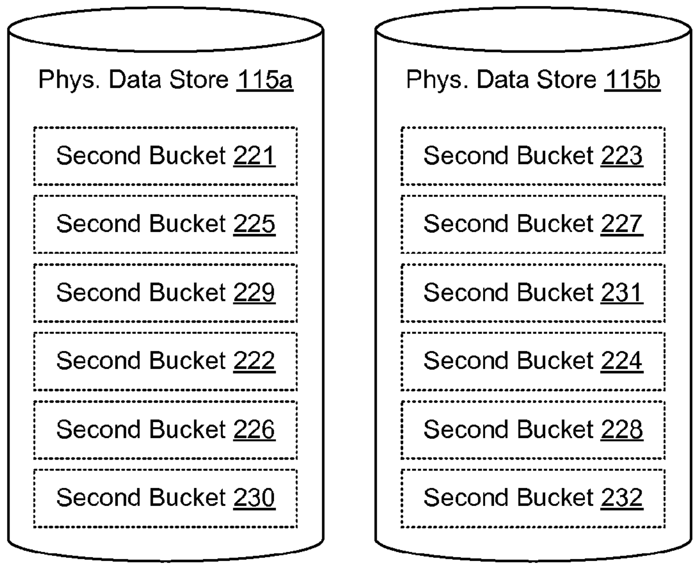
Phys. Data Store 115a
Second Bucket 221
Second Bucket 225
Second Bucket 229
Second Bucket 222
Second Bucket 226
Second Bucket 230
Phys. Data Store 115b
Second Bucket 223
Second Bucket 227
Second Bucket 231
Second Bucket 224
Second Bucket 228
Second Bucket 232

FIG. 2C

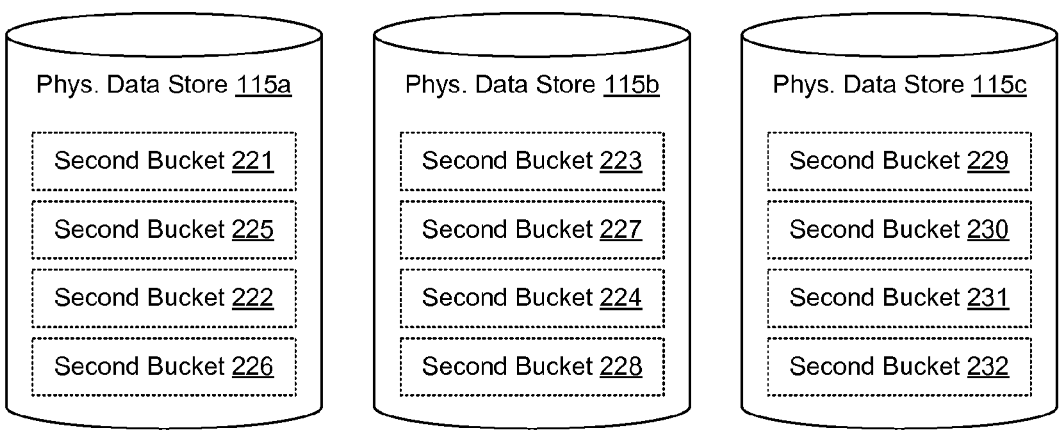
Phys. Data Store 115a
Second Bucket 221
Second Bucket 225
Second Bucket 222
Second Bucket 226
Phys. Data Store 115b
Second Bucket 223
Second Bucket 227
Second Bucket 224
Second Bucket 228
Phys. Data Store 115c
Second Bucket 229
Second Bucket 230
Second Bucket 231
Second Bucket 232

FIG. 2D

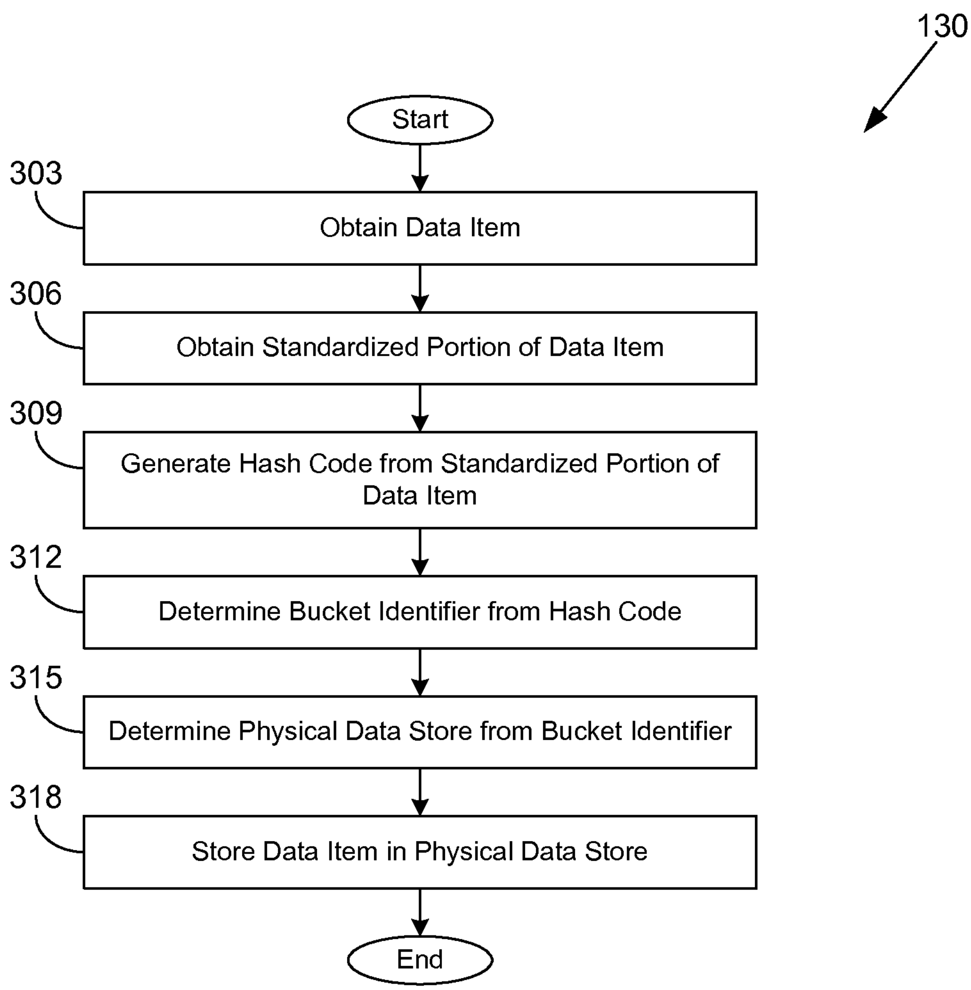
130
Start
303
Obtain Data Item
306
Obtain Standardized Portion of Data Item
309
Generate Hash Code from Standardized Portion of Data Item
312
Determine Bucket Identifier from Hash Code
315
Determine Physical Data Store from Bucket Identifier
318
Store Data Item in Physical Data Store
End

FIG. 3A

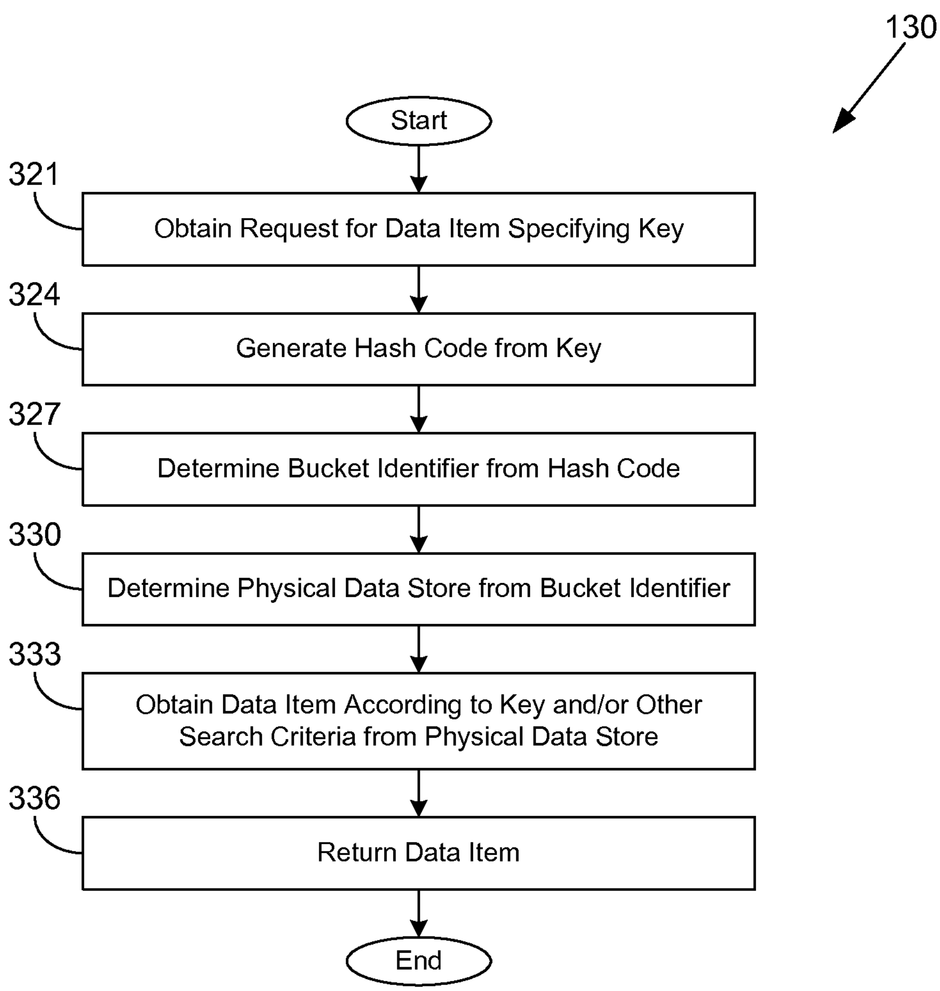
130
Start
321
Obtain Request for Data Item Specifying Key
324
Generate Hash Code from Key
327
Determine Bucket Identifier from Hash Code
330
Determine Physical Data Store from Bucket Identifier
333
Obtain Data Item According to Key and/or Other Search Criteria from Physical Data Store
336
Return Data Item
End

FIG. 3B

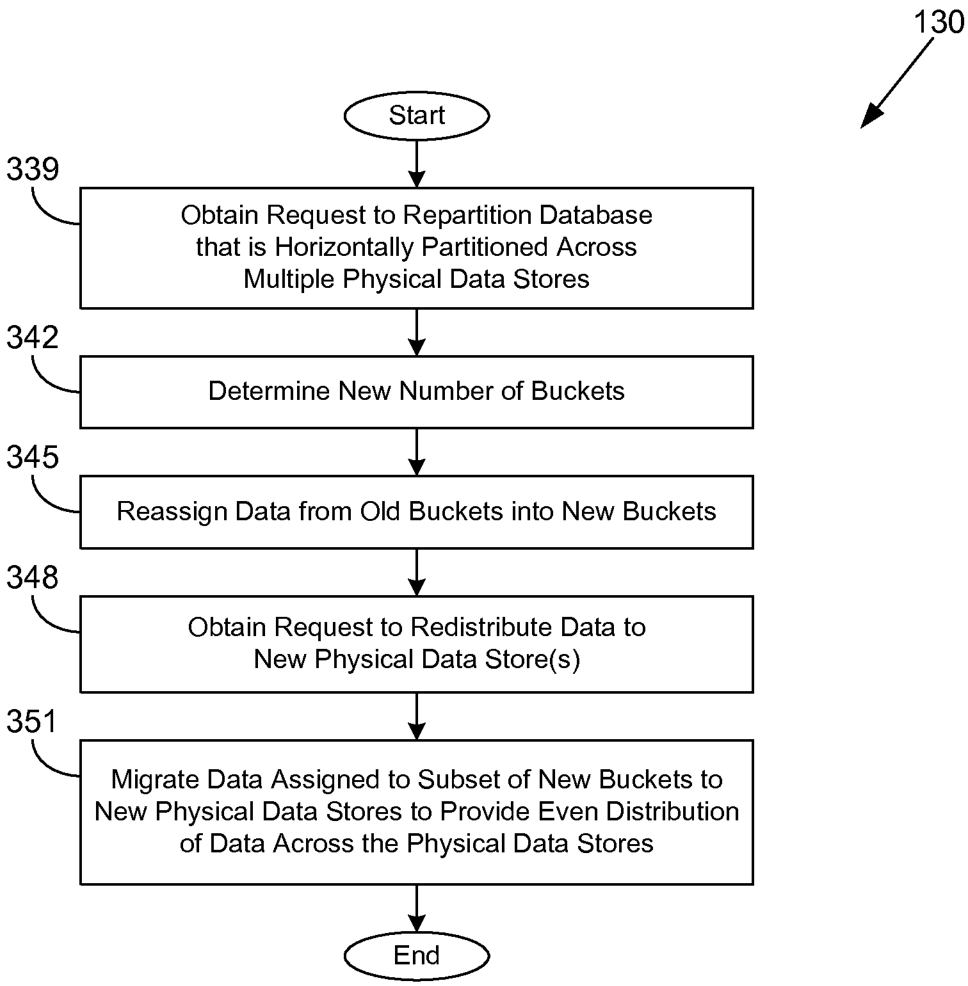
130
Start
339
Obtain Request to Repartition Database that is Horizontally Partitioned Across Multiple Physical Data Stores
342
Determine New Number of Buckets
345
Reassign Data from Old Buckets into New Buckets
348
Obtain Request to Redistribute Data to New Physical Data Store(s)
351
Migrate Data Assigned to Subset of New Buckets to New Physical Data Stores to Provide Even Distribution of Data Across the Physical Data Stores
End

FIG. 3C

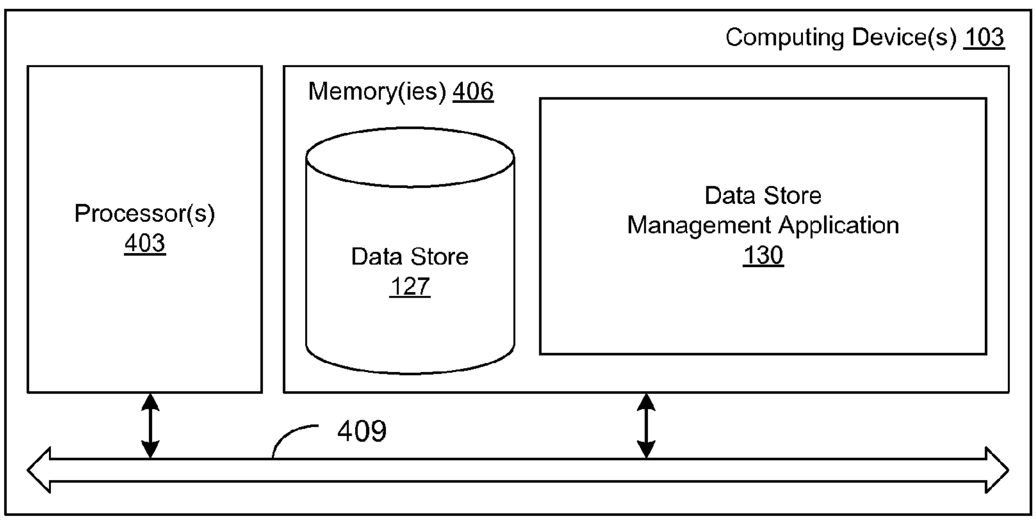
Computing Device(s) 103
Memory(ies) 406
Processor(s)
403
Data Store
127
Data Store
Management Application
130
409

FIG. 4

FACILITATING DATA REDISTRIBUTION IN DATABASE SHARDING

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of, and claims priority to, co-pending U.S. Patent Application entitled "FACILITATING DATA REDISTRIBUTION IN DATABASE SHARDING," filed on Sep. 27, 2011, and assigned application Ser. No. 13/246,371, which is incorporated herein by reference in its entirety.

BACKGROUND

Sharding refers to the horizontal partitioning of a database among multiple physical data stores. In relational database management systems, data is organized into tables containing rows and columns. Each row corresponds to an instance of a data item, and each column corresponds to an attribute for the data item. Sharding produces partitions by rows instead of columns. Through partitioning, the data in a single table may be spread among potentially many different physical data stores, thereby improving scalability.

BRIEF DESCRIPTION OF THE DRAWINGS

Many aspects of the present disclosure can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the disclosure. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

FIG. **1** is a drawing of a networked environment according to various embodiments of the present disclosure.

FIGS. **2**A-**2**D are drawings depicting various stages of data redistribution among physical data stores in the networked environment of FIG. **1** according to various embodiments of the present disclosure.

FIGS. **3**A-**3**C are flowcharts illustrating examples of functionality implemented as portions of a data store management application executed in a computing device in the networked environment of FIG. **1** according to various embodiments of the present disclosure.

FIG. **4** is a schematic block diagram that provides one example illustration of a computing device employed in the networked environment of FIG. **1** according to various embodiments of the present disclosure.

DETAILED DESCRIPTION

The present disclosure relates to facilitating data redistribution in database sharding. In database sharding, data items from a database may be organized into "buckets," which are then mapped to physical data stores. For example, the primary key, or a portion thereof, for a data item may be hashed, thereby generating a hash code. The modulo operator may be applied, with the hashcode being the dividend and the number of buckets being the divisor. The resulting remainder may be used to assign the data item to one of the buckets. This approach yields an even distribution of the primary keys among the buckets. For even distribution of the primary keys among the data stores, the number of buckets is a multiple of the number of data stores.

Various embodiments of the present disclosure facilitate data redistribution when the number of data stores is increased. If the number of data stores is to be increased, the number of buckets is also increased if the number of buckets is not a multiple of the number of data stores. Accordingly, a new number of buckets may be generated, where the new number of buckets is a multiple of the new number of data stores. The data items are reassigned to the new buckets and remain in place in their respective data stores under the existing mapping. Subsequently, data corresponding to some of the buckets may be relocated to the new data stores. In the following discussion, a general description of the system and its components is provided, followed by a discussion of the operation of the same.

With reference to FIG. **1**, shown is a networked environment **100** according to various embodiments. The networked environment **100** includes one or more computing devices **103** in data communication with a plurality of computing devices **106***a*, **106***b* . . . **106**N and one or more clients **109** by way of a network **112**. The network **112** includes, for example, the Internet, intranets, extranets, wide area networks (WANs), local area networks (LANs), wired networks, wireless networks, or other suitable networks, etc., or any combination of two or more such networks.

The computing devices **106** may each comprise, for example, a server computer or any other system providing computing capability. Alternatively, each of the computing devices **106** may represent a plurality of computing devices **106** may be employed that are arranged, for example, in one or more server banks or computer banks or other arrangements. For example, a plurality of computing devices **106** together may comprise a cloud computing resource, a grid computing resource, and/or any other distributed computing arrangement. Such computing devices **106** may be located in a single installation or may be distributed among many different geographical locations. For purposes of convenience, each computing device **106** is referred to herein in the singular. Even though each computing device **106** is referred to in the singular, it is understood that a plurality of computing devices **106** may be employed in the various arrangements as described above. Each of the computing devices **106** includes one or more data storage devices.

Each of the computing devices **106** includes a respective one of a plurality of physical data stores **115***a*, **115***b* . . . **115**N. The physical data stores **115** collectively store a horizontally partitioned database **118**. The respective data from the database **118** that is stored by each one of the physical data stores **115** may be referred to as a shard or a horizontal partition. Such a shard or horizontal partition corresponds to a plurality of buckets **121**. In some embodiments, multiple physical data stores **115** may be hosted by one computing device **106**. However, in other embodiments, the physical data stores **115** may be hosted by distinct computing devices **106** to improve performance and scalability. In some of these embodiments, a single physical data store **115** may be hosted by multiple computing devices **106** to further improve performance.

The buckets **121** stored by the physical data store **115***a* comprise a plurality of buckets **121** as . . . **121***a*N. The buckets **121** stored by the physical data store **115***b* comprise a plurality of buckets **121***ba* . . . **121***b*N. The buckets **121** stored by the physical data store **115**N comprise a plurality of buckets **121**Na . . . **121**NN. Each bucket **121** corresponds to a respective grouping of a plurality of data items **124***a*, **124***b* . . . **124**N from the database **118**. With a database **118** that is a relational database, the data items **124** may correspond to rows from one or more tables. The data items **124** are assigned to particular buckets **121** using a modulus-based mapping to distribute the data items **124** evenly across the buckets **121**. The buckets **121**, in turn, are mapped to one of the physical data stores **115**.

The computing device **103** may comprise, for example, a server computer or any other system providing computing capability. Alternatively, a plurality of computing devices **103** may be employed that are arranged, for example, in one or more server banks or computer banks or other arrangements. For example, a plurality of computing devices **103** together may comprise a cloud computing resource, a grid computing resource, and/or any other distributed computing arrangement. Such computing devices **103** may be located in a single installation or may be distributed among many different geographical locations. For purposes of convenience, the computing device **103** is referred to herein in the singular. Even though the computing device **103** is referred to in the singular, it is understood that a plurality of computing devices **103** may be employed in the various arrangements as described above.

Various applications and/or other functionality may be executed in the computing device **103** according to various embodiments. Also, various data is stored in a data store **127** that is accessible to the computing device **103**. The data store **127** may be representative of a plurality of data stores **127** as can be appreciated. The data stored in the data store **127**, for example, is associated with the operation of the various applications and/or functional entities described below.

The components executed on the computing device **103**, for example, include a data store management application **130** and other applications, services, processes, systems, engines, or functionality not discussed in detail herein. The data store management application **130** is executed to maintain the database **118** stored in the physical data stores **115**. To this end, the data store management application **130** is configured to store data items **124** in the database **118** and obtain data items **124** or portions thereof from the database **118**. The data store management application **130** also may repartition the database **118** into buckets **121** and add or remove physical data stores **115** with redistribution of data from the database **118** as will be described.

The data stored in the data store **127** includes, for example, a bucket to physical data store mapping **133**, a bucket assignment configuration **136**, and potentially other data. The bucket to physical data store mapping **133** defines which buckets **121** are stored in which physical data stores **115**. The bucket assignment configuration **136** controls assignment of data items **124** to buckets **121** by the data store management application **130**. Additionally, the bucket assignment configuration **136** may be used to determine a bucket **121** to which a data item **124** has been assigned.

The client **109** is representative of a plurality of client devices that may be coupled to the network **112**. The client **109** may comprise, for example, a processor-based system such as a computer system. Such a computer system may be embodied in the form of a desktop computer, a server computer, a laptop computer, personal digital assistants, cellular telephones, smartphones, set-top boxes, music players, web pads, tablet computer systems, game consoles, electronic book readers, or other devices with like capability. The client **109** may include a display comprising, for example, one or more devices such as cathode ray tubes (CRTs), liquid crystal display (LCD) screens, gas plasma-based flat panel displays, LCD projectors, or other types of display devices, etc.

The client **109** may be configured to execute various applications such as a data store client application **139** and/or other applications. The data store client application **139** is employed to access data items **124** or portions thereof which are stored in the database **118**. The data store client application **139** may also store and/or update data items **124** stored in the database **118**. The data store client application **139** may employ structured query language (SQL) and/or other interfaces. In some embodiments, the data store client application **139** may be executed in the computing device **103**. The client **109** may be configured to execute applications beyond the data store client application **139** such as, for example, browser applications, mobile applications, email applications, instant message applications, and/or other applications.

Next, a general description of the operation of the various components of the networked environment **100** is provided. To begin, a database **118** is configured to use multiple physical data stores **115** to store data. The database **118** is partitioned into buckets **121**, with at least one bucket **121** being stored in each physical data store **115**. The same number of buckets **121** are stored in each physical data store **115** to facilitate equal distribution of data items **124** to the physical data stores **115**. The bucket to physical data store mapping **133** records which of the buckets **121** are stored in which of the physical data stores **115**.

Data items **124** are assigned to buckets **121** through a procedure controlled by the bucket assignment configuration **136**. For example, a key or other standardized portion of a data item **124** may be hashed, and the resulting hash value may be assigned to one of the buckets **121** using a modulo-based assignment. The modulo-based assignment may be stored in association with the data item **124** or determined dynamically in response to accessing the data item **124**.

In one non-limiting example, the database **118** stores data relating to an electronic marketplace with multiple merchants. It may be desired that the data of each merchant be stored in one physical data store **115**. Thus, the data items **124** stored by the merchant may include a merchant identifier. The bucket **121** assignment may be derived from the merchant identifier to ensure that data of the merchant is stored in one bucket **121** and one physical data store **115**.

After the database **118** is initially configured, an increased number of buckets **121** may be desired for various reasons. For example, it may be easier to backup the database **118** if it is partitioned into a greater number of buckets **121** with each bucket **121** holding less data. To this end, the number of buckets **121** may be increased by some multiple of the number of buckets **121** so that each bucket **121** is divided into the same number of smaller buckets **121**. The multiple may be selected in order to migrate buckets **121** to additional physical data stores **115**. However, no data migration is necessary to accomplish repartitioning into a new number of buckets **121**. An example of bucket **121** repartitioning and data migration to additional physical data stores **115** will next be described in connection with the following four figures.

Turning now to FIGS. **2**A-**2**D, shown are drawings depicting various stages of data redistribution among a plurality of physical data stores **115** in the networked environment **100** (FIG. **1**) according to various embodiments. FIG. **2**A shows two physical data stores **115***a* and **115***b* which are used to store data items **124** (FIG. **1**) from a database **118** (FIG. **1**). The physical data store **115***a* is mapped to two first buckets **211** and **212**. The physical data store **115***b* is also mapped to two first buckets **213** and **214**. It is noted that each physical data store **115** is mapped to an equal number of buckets **121** (FIG. **1**) to provide for an equal distribution of data assignments across the physical data stores **115**. At the least, each physical data store **115** will have one bucket **121**, but a physical data store **115** may store many buckets **121** in some cases.

FIG. **2**B illustrates the physical data stores **115***a* and **115***b* from FIG. **2**A after repartitioning to increase the number of buckets **121** (FIG. **1**). The buckets **121** according to the previous configuration are referred to as first buckets **121**, while the buckets **121** according to the new configuration are referred to second buckets **121**. In the non-limiting example of FIG. **2**B, each first bucket **121** is divided into three second buckets **121**. In the physical data store **115***a*, the first bucket **211** is divided into second buckets **221**, **225**, and **229**, and the first bucket **212** is divided into second buckets **222**, **226**, and **230**. In the physical data store **115***b*, the first bucket **213** is divided into second buckets **223**, **227**, and **231**, and the first bucket **214** is divided into second buckets **224**, **228**, and **232**.

It is noted that each one of the first buckets **211**, **212**, **213**, and **214** is divided into the same number of second buckets **121**. The total number of second buckets **121** may be selected, for example, to be a multiple of a new number of physical data stores **115**. Also, in this non-limiting example, the identifier for each second bucket **121** may be derived from the identifier for the respective first bucket **121**.

To illustrate, the first bucket **212** may have an identifier i**1** of "2." The identifiers i2 of the second buckets **222**, **226**, and **230** may be determined according to the equation: $i2=i1+k*n$, where k is the number of first buckets **121** and n is a non-negative integer less than the number of second buckets **121** divided by k. Here, k equals 4, the number of second buckets **121** equals 12, and n equals the set of $\{0, 1, 2\}$. Therefore, the set of i**2** is $\{2, 6, 10\}$, which corresponds to the identifiers for second buckets **222**, **226**, and **230**. It is noted that the reference numerals for the second buckets **121** are intentionally selected to be **220** plus the identifier described above, to fit with this example.

FIG. **2**C illustrates the result of this repartitioning. The physical data store **115***a* stores the second buckets **221**, **225**, **229**, **222**, **226**, and **230**. The physical data store **115***b* stores the second buckets **223**, **227**, **231**, **224**, **228**, and **232**. It is noted that each of the physical data stores **115***a* and **115***b* stores an equal number of buckets **121** (FIG. **1**), which facilitates an equal distribution of data items **124** (FIG. **1**) to each of the physical data stores **115**.

FIG. **2**D depicts the addition of a new physical data store **115***c* and a redistribution of data items **124** (FIG. **1**) from the other physical data stores **115***a* and **115***b* to the physical data store **115***c*. In FIG. **2**D, the second buckets **229**, **230**, **231**, and **232** have been migrated to the physical data store **115***c*, with the second buckets **229** and **230** coming from the physical data store **115***a* and the second buckets **231** and **232** coming from the physical data store **115***b* (see FIG. **2**C). An equal number of buckets **121** (FIG. **1**) are migrated from each of the physical data stores **115***a* and **115***b*, with the result being that each of the physical data stores **115***a*, **115***b*, and **115***c* stores an equal number of buckets **121** after the redistribution. Although specific buckets **121** are illustrated as being moved to the physical data stores **115***c* in this example, any four of the buckets **121** may be moved as desired.

Referring next to FIG. **3**A, shown is a flowchart that provides one example of the operation of a portion of the data store management application **130** according to various embodiments. In particular, the flowchart of FIG. **3**A relates to storage of a data item **124** (FIG. **1**) in the database **118** (FIG. **1**). It is understood that the flowchart of FIG. **3**A provides merely an example of the many different types of functional arrangements that may be employed to implement the operation of the portion of the data store management application **130** as described herein. As an alternative, the flowchart of FIG. **3**A may be viewed as depicting an example of steps of a method implemented in the computing device **103** (FIG. **1**) according to one or more embodiments.

Beginning with box **303**, the data store management application **130** obtains a data item **124**. For example, the data item **124** may be supplied by a data store client application **139** (FIG. **1**) as part of an SQL insert or update statement. In box **306**, the data store management application **130** obtains a standardized portion of the data item **124**. The standardized portion may correspond, for example, to a primary key or a portion thereof. In box **309**, the data store management application **130** generates a hash code by applying a hash function to the standardized portion of the data item **124**.

In box **312**, the data store management application **130** determines a bucket identifier from the hash code. The bucket identifier uniquely identifies a bucket **121** (FIG. **1**). In one embodiment, the data store management application **130** applies the modulus operation to the hash code, which is used as the dividend, and to the number of buckets, which is used as the divisor. The result of the modulus operation may be used directly as the bucket identifier or may be transformed in some way to arrive at the bucket identifier. In another embodiment, the bucket identifier may be determined according to a mapping of data items **124** to buckets **121**. The determination of the bucket identifier may be controlled in part by settings in the bucket assignment configuration **136** (FIG. **1**).

In box **315**, the data store management application **130** determines a physical data store **115** (FIG. **1**) from the bucket identifier. To this end, the data store management application **130** may consult the bucket to physical data store mapping **133** (FIG. **1**). In box **318**, the data store management application **130** stores, or updates, the data item **124** in the physical data store **115** determined in box **315**. In one embodiment, the data store management application **130** may store the bucket identifier along with the data item **124**. Thereafter, the portion of the data store management application **130** ends.

Turning now to FIG. **3**B, shown is a flowchart that provides one example of the operation of another portion of the data store management application **130** according to various embodiments. Specifically, the flowchart of FIG. **3**B relates to obtaining a data item **124** (FIG. **1**) from a database **118** (FIG. **1**). It is understood that the flowchart of FIG. **3**B provides merely an example of the many different types of functional arrangements that may be employed to implement the operation of the other portion of the data store management application **130** as described herein. As an alternative, the flowchart of FIG. **3**B may be viewed as depicting an example of steps of a method implemented in the computing device **103** (FIG. **1**) according to one or more embodiments.

Beginning with box **321**, the data store management application **130** obtains a request for a data item **124**, where the request specifies a key that identifies the data item **124**. For example, the request may be obtained from a data store client application **139** (FIG. **1**) and may correspond to a select SQL statement. In box **324**, the data store management application **130** generates a hash code by applying a hash function to the key or a portion of the key.

In box **327**, the data store management application **130** determines a bucket identifier from the hash code. In one embodiment, the data store management application **130** may apply a modulus operation to determine the bucket identifier, i.e., the bucket identifier equals the hash code modulo the number of buckets **121** (FIG. **1**). The result of the modulus operation may be transformed in some way to arrive at the bucket identifier. The determination of the bucket identifier from the key may be controlled at least in part by stored settings in the bucket assignment configuration **136** (FIG. **1**).

In box **330**, the data store management application **130** determines a physical data store **115** (FIG. **1**) from the bucket identifier according to the bucket to physical data store mapping **133** (FIG. **1**). In box **333**, the data store management application **130** obtains the data item **124** according to the key and/or other search criteria from the physical data store **115** determined in box **330**. In box **336**, the data store management application **130** returns the data item **124**. Thereafter, the portion of the data store management application **130** ends.

Moving on to FIG. **3**C, shown is a flowchart that provides one example of the operation of yet another portion of the data store management application **130** according to various embodiments. In particular, the flowchart of FIG. **3**C relates to the redistribution of data items **124** (FIG. **1**) in the database **118** (FIG. **1**) considering the addition of one or more new physical data stores **115** (FIG. **1**). It is understood that the flowchart of FIG. **3**C provides merely an example of the many different types of functional arrangements that may be employed to implement the operation of the other portion of the data store management application **130** as described herein. As an alternative, the flowchart of FIG. **3**C may be viewed as depicting an example of steps of a method implemented in the computing device **103** (FIG. **1**) according to one or more embodiments.

Beginning with box **339**, the data store management application **130** obtains a request to repartition a database **118** that is horizontally partitioned across multiple physical data stores **115**. For example, the request may be obtained from the data store client application **139** (FIG. **1**). In box **342**, the data store management application **130** determines a new number of buckets **121** (FIG. **1**).

In one example, the new number of buckets **121** may be selected to be a multiple of the existing number of buckets **121** and of a new number of physical data stores **115**. In another example, the new number of buckets **121** may be selected to be a multiple of the existing number of buckets **121** plus a positive integer. In yet another example, the new number of buckets **121** may be selected to be a multiple of the sum of a positive integer and the previous quantity of the physical data stores **115**.

Once the new number of buckets **121** is determined, the data store management application **130** reassigns data items **124** from the old bucketing arrangement to the new bucketing arrangement in box **345**. In this reassignment, the data items **124** remain unmoved among the physical data stores **115**. In one embodiment, new bucket identifiers may be stored along with the data items **124** in the database **118**. In another embodiment, the bucket assignment configuration **136** (FIG. **1**) is updated so that dynamically generated bucket identifiers correspond to the new bucket identifiers.

In box **348**, the data store management application **130** obtains a request to redistribute data items **124** to newly added physical data stores **115**. Such a request may automatically follow the bucket **121** reassignment or may be manually generated by a data store client application **139** (FIG. **1**). In box **351**, the data store management application **130** migrates data items **124** that are assigned to a subset of the new buckets **121** to the new physical data stores **115**. The quantity of the buckets **121** moved to each new physical data store corresponds to the number of buckets **121** divided by the total number of physical data stores **115**. The migration provides for an even distribution of the data items **124** across the physical data stores **115**. Thereafter, the portion of the data store management application **130** ends.

With reference to FIG. **4**, shown is a schematic block diagram of the computing device **103** according to an embodiment of the present disclosure. The computing device **103** includes at least one processor circuit, for example, having a processor **403** and a memory **406**, both of which are coupled to a local interface **409**. To this end, the computing device **103** may comprise, for example, at least one server computer or like device. The local interface **409** may comprise, for example, a data bus with an accompanying address/control bus or other bus structure as can be appreciated.

Stored in the memory **406** are both data and several components that are executable by the processor **403**. In particular, stored in the memory **406** and executable by the processor **403** are the data store management application **130** and potentially other applications. Also stored in the memory **406** may be a data store **127** and other data. In addition, an operating system may be stored in the memory **406** and executable by the processor **403**.

It is understood that there may be other applications that are stored in the memory **406** and are executable by the processor **403** as can be appreciated. Where any component discussed herein is implemented in the form of software, any one of a number of programming languages may be employed such as, for example, C, C++, C#, Objective C, Java®, JavaScript®, Perl, PHP, Visual Basic®, Python®, Ruby, Delphi®, Flash®, or other programming languages.

A number of software components are stored in the memory **406** and are executable by the processor **403**. In this respect, the term "executable" means a program file that is in a form that can ultimately be run by the processor **403**. Examples of executable programs may be, for example, a compiled program that can be translated into machine code in a format that can be loaded into a random access portion of the memory **406** and run by the processor **403**, source code that may be expressed in proper format such as object code that is capable of being loaded into a random access portion of the memory **406** and executed by the processor **403**, or source code that may be interpreted by another executable program to generate instructions in a random access portion of the memory **406** to be executed by the processor **403**, etc. An executable program may be stored in any portion or component of the memory **406** including, for example, random access memory (RAM), read-only memory (ROM), hard drive, solid-state drive, USB flash drive, memory card, optical disc such as compact disc (CD) or digital versatile disc (DVD), floppy disk, magnetic tape, or other memory components.

The memory **406** is defined herein as including both volatile and nonvolatile memory and data storage components. Volatile components are those that do not retain data values upon loss of power. Nonvolatile components are those that retain data upon a loss of power. Thus, the memory **406** may comprise, for example, random access memory (RAM), read-only memory (ROM), hard disk drives, solid-state drives, USB flash drives, memory cards accessed via a memory card reader, floppy disks accessed via an associated floppy disk drive, optical discs accessed via an optical disc drive, magnetic tapes accessed via an appropriate tape drive, and/or other memory components, or a combination of any two or more of these memory components. In addition, the RAM may comprise, for example, static random access memory (SRAM), dynamic random access memory (DRAM), or magnetic random access memory (MRAM) and other such devices. The ROM may comprise, for example, a programmable read-only memory (PROM), an erasable programmable read-only memory (EPROM), an electrically erasable programmable read-only memory (EEPROM), or other like memory device.

Also, the processor **403** may represent multiple processors **403** and the memory **406** may represent multiple memories **406** that operate in parallel processing circuits, respectively. In such a case, the local interface **409** may be an appropriate network that facilitates communication between any two of the multiple processors **403**, between any processor **403** and any of the memories **406**, or between any two of the memories

406, etc. The local interface 409 may comprise additional systems designed to coordinate this communication, including, for example, performing load balancing. The processor 403 may be of electrical or of some other available construction.

Although data store management application 130, the data store client application 139 (FIG. 1), and other various systems described herein may be embodied in software or code executed by general purpose hardware as discussed above, as an alternative the same may also be embodied in dedicated hardware or a combination of software/general purpose hardware and dedicated hardware. If embodied in dedicated hardware, each can be implemented as a circuit or state machine that employs any one of or a combination of a number of technologies. These technologies may include, but are not limited to, discrete logic circuits having logic gates for implementing various logic functions upon an application of one or more data signals, application specific integrated circuits having appropriate logic gates, or other components, etc. Such technologies are generally well known by those skilled in the art and, consequently, are not described in detail herein.

The flowcharts of FIGS. 3A-3C show the functionality and operation of an implementation of portions of the data store management application 130. If embodied in software, each block may represent a module, segment, or portion of code that comprises program instructions to implement the specified logical function(s). The program instructions may be embodied in the form of source code that comprises human-readable statements written in a programming language or machine code that comprises numerical instructions recognizable by a suitable execution system such as a processor 403 in a computer system or other system. The machine code may be converted from the source code, etc. If embodied in hardware, each block may represent a circuit or a number of interconnected circuits to implement the specified logical function(s).

Although the flowcharts of FIGS. 3A-3C show a specific order of execution, it is understood that the order of execution may differ from that which is depicted. For example, the order of execution of two or more blocks may be scrambled relative to the order shown. Also, two or more blocks shown in succession in FIGS. 3A-3C may be executed concurrently or with partial concurrence. Further, in some embodiments, one or more of the blocks shown in 3A-3C may be skipped or omitted. In addition, any number of counters, state variables, warning semaphores, or messages might be added to the logical flow described herein, for purposes of enhanced utility, accounting, performance measurement, or providing troubleshooting aids, etc. It is understood that all such variations are within the scope of the present disclosure.

Also, any logic or application described herein, including the data store management application 130 and the data store client application 139, that comprises software or code can be embodied in any non-transitory computer-readable medium for use by or in connection with an instruction execution system such as, for example, a processor 403 in a computer system or other system. In this sense, the logic may comprise, for example, statements including instructions and declarations that can be fetched from the computer-readable medium and executed by the instruction execution system. In the context of the present disclosure, a "computer-readable medium" can be any medium that can contain, store, or maintain the logic or application described herein for use by or in connection with the instruction execution system. The computer-readable medium can comprise any one of many physical media such as, for example, magnetic, optical, or semiconductor media. More specific examples of a suitable computer-readable medium would include, but are not limited to, magnetic tapes, magnetic floppy diskettes, magnetic hard drives, memory cards, solid-state drives, USB flash drives, or optical discs. Also, the computer-readable medium may be a random access memory (RAM) including, for example, static random access memory (SRAM) and dynamic random access memory (DRAM), or magnetic random access memory (MRAM). In addition, the computer-readable medium may be a read-only memory (ROM), a programmable read-only memory (PROM), an erasable programmable read-only memory (EPROM), an electrically erasable programmable read-only memory (EEPROM), or other type of memory device.

It should be emphasized that the above-described embodiments of the present disclosure are merely possible examples of implementations set forth for a clear understanding of the principles of the disclosure. Many variations and modifications may be made to the above-described embodiment(s) without departing substantially from the spirit and principles of the disclosure. All such modifications and variations are intended to be included herein within the scope of this disclosure and protected by the following claims.

Therefore, the following is claimed:

1. A non-transitory computer-readable medium embodying a program executable in a computing device, wherein when executed the program causes the computing device to at least:

maintain a database that is stored in a plurality of physical data stores through horizontal partitioning, the database including a plurality of data items;

assign individual ones of the plurality of data items to individual ones of a plurality of first buckets by generating a respective hash code from a standardized portion of the individual one of the plurality of data items and determining the respective hash code modulo the number of the plurality of first buckets, wherein a first fixed number of the plurality of first buckets are stored in corresponding ones of the plurality of physical data stores according to a mapping;

reassign the individual ones of the plurality of data items to individual ones of a plurality of second buckets by determining the respective hash code modulo the number of the plurality of second buckets, the number of the plurality of second buckets being a multiple of the number of first buckets in the plurality of first buckets, a multiple of a current number of physical data stores, and a multiple of an increased number of physical data stores; and

update the mapping to map a second fixed number of the plurality of second buckets to corresponding ones of the plurality of physical data stores, wherein the plurality of data items are unmoved between the plurality of physical data stores by updating the mapping.

2. The non-transitory computer-readable medium of claim 1, wherein when executed the program further causes the computing device to at least determine one of the plurality of physical data stores in which a given one of the plurality of data items is stored by:

generating the respective hash code for the given one of the plurality of data items;

generating a second bucket identifier based at least in part on the respective hash code modulo the number of the plurality of second buckets; and

determining the one of the plurality of physical data stores that corresponds to the second bucket identifier according to the mapping.

3. The non-transitory computer-readable medium of claim 1, wherein when executed the program further causes the

computing device to at least: add at least one physical data store to the plurality of physical data stores;

migrate the data items which are assigned to a subset of the plurality of second buckets to the at least one physical data store that has been added; and

update the mapping to map a third fixed number of the plurality of second buckets to corresponding ones of the plurality of physical data stores, wherein an even distribution of the plurality of second buckets is achieved among the plurality of physical data stores.

4. A system, comprising:

a plurality of physical data stores;

at least one computing device including a processor and a memory; and

a data store management application executable in the at least one computing device, wherein when executed the data store management application causes the at least one computing device to at least:

maintain a database of data that is horizontally partitioned into a set of first buckets using modulo-based assignments, a fixed number of the set of first buckets being stored in individual ones of the plurality of physical data stores; and

repartition the database into a set of second buckets using modulo-based assignments, the number of second buckets in the set of second buckets being a multiple of the number of first buckets in the set of first buckets, a multiple of a current number of physical data stores, and a multiple of an increased number of physical data stores, wherein the data in the database is unmoved between the plurality of physical data stores by repartitioning.

5. The system of claim **4**, wherein when executed the data store management application further causes the at least one computing device to at least determine a modulo-based assignment for a data item in the database by generating a hash code from a standardized portion of the data item and calculating the modulo-based assignment based at least in part on a result of the hash code modulo a quantity of buckets.

6. The system of claim **5**, wherein the standardized portion of the data item corresponds to a key.

7. The system of claim **4**, wherein the fixed number is an integer greater than one.

8. The system of claim **4**, wherein the modulo-based assignments are stored in association with the data.

9. The system of claim **4**, wherein the modulo-based assignments are determined dynamically in response to accessing the data.

10. The system of claim **4**, wherein when executed the data store management application further causes the at least one computing device to at least:

add at least one other physical data store to the plurality of physical data stores; and

migrate the data in the database corresponding to a subset of the set of second buckets to the at least one other physical data store.

11. The system of claim **10**, wherein migrating the data further comprises updating a mapping of the set of second buckets to the plurality of physical data stores.

12. A method, comprising:

maintaining a plurality of physical data stores corresponding to horizontal partitions of a database containing a plurality of data items, wherein the plurality of data items are assigned to respective ones of a plurality of first buckets, and the data items assigned to a respective first bucket are stored in a mapped one of the plurality of physical data stores; and

reassigning, via a computing device, for individual ones of the plurality of first buckets, the data items which are assigned to the first bucket to a second bucket in a corresponding subset of a plurality of second buckets, the corresponding subset of the plurality of second buckets being distinct for each first bucket, the second buckets in the corresponding subset being stored in the mapped one of the plurality of physical data stores corresponding to the first bucket, the number of second buckets in the corresponding subset being a fixed number for all of the plurality of first buckets, the number of second buckets in the plurality of second buckets being a multiple of the number of first buckets in the plurality of first buckets, a multiple of a current number of physical data stores, and a multiple of an increased number of physical data stores.

13. The method of claim **12**, wherein an individual one of the plurality of data items is associated with a key, and the method further comprises assigning, by the computing device, the individual one of the plurality of data items to one of the plurality of first buckets by:

generating, by the computing device, a hash code from the key of the individual one of the plurality of data items;

determining, by the computing device, a first bucket identifier by calculating the hash code modulo the number of the plurality of first buckets; and

assigning, by the computing device, the individual one of the plurality of data items to the one of the plurality of first buckets corresponding to the first bucket identifier.

14. The method of claim **13**, wherein assigning, by the computing device, the individual one of the plurality of data items to the one of the plurality of first buckets corresponding to the first bucket identifier further comprises storing, by the computing device, the first bucket identifier in association with the individual one of the plurality of data items.

15. The method of claim **12**, wherein an individual one of the plurality of data items is associated with a key, and reassigning further comprises:

for the individual one of the plurality of data items:

generating, by the computing device, a hash code from the key of the individual one of the plurality of data items;

determining, by the computing device, a second bucket identifier by calculating the hash code modulo the number of second buckets; and

reassigning, by the computing device, the individual one of the plurality of data items to the second bucket corresponding to the second bucket identifier.

16. The method of claim **15**, wherein reassigning, by the computing device, the individual one of the plurality of data items to the second bucket corresponding to the second bucket identifier further comprises storing, by the computing device, the second bucket identifier in association with the individual one of the plurality of data items, the second bucket identifier replacing a first bucket identifier.

17. The method of claim **12**, further comprising:

adding, by the computing device, at least one physical data store to the plurality of physical data stores.

18. The method of claim **17**, further comprising migrating, by the computing device, the data items that are assigned to a second bucket in the corresponding subset of second buckets from the mapped one of the plurality of physical data stores to the at least one physical data store that has been added.

19. The method of claim **12**, further comprising determining, by the computing device, one of the plurality of physical data stores in which a given one of the plurality of data items is stored by:

generating, by the computing device, a hash code for the given one of the plurality of data items;

generating, by the computing device, a second bucket identifier based at least in part on the hash code modulo the number of second buckets; and

determining, by the computing device, the one of the plurality of physical data stores that corresponds to the second bucket identifier.

20. The method of claim **12**, wherein the plurality of data items are unmoved between the plurality of physical data stores by the reassigning.

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